17th Eur. PV Solar Energy Conf.
Munich, Germany
Oct., 2001

CONDUCTIVE ADHESIVES FOR INTERCONNECTION OF BUSBARLESS EMITTER WRAP-THROUGH SOLAR CELLS ON A STRUCTURED METAL FOIL

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ABSTRACT: The objective of this work was to make a 16% efficient screen-printed emitter wrap-through (EWT) solar module. For this purpose the busbars on the rear of the EWT cell were omitted, which maximises the useful cell area and the efficiency. The busbars' current collecting task is taken over by a special rear side interconnection foil on to which each metal finger is connected by conductive adhesives. This foil also serves as a rear side moisture barrier. In this paper the processing of busbarless EWT cells and the interconnection in a module are described with a special focus on the use of conductive adhesives. Busbarless EWT cells with an efficiency up to 15.6% have been processed and single cell laminates have sucessfully been made. Ongoing extensive climate tests have shown no significant degradation so far.
Keywords: Module Manufacturing – 1: Contact – 2: Silicon- 3

1. INTRODUCTION

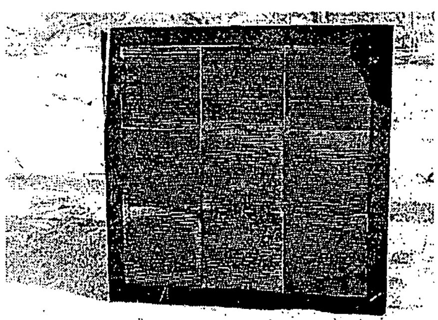

Figure 1: Busbarless EWT test module. No metallisation on front gives homogeneous appearance and no shadow losses.

Emitter wrap-through solar cells [1, 2, 3] are a attractive solar cell design for future large scale production of PV modules. With both contacts on the back, and no metallisation on the front they boast esthetic, homogenous appearance and do not suffer from shadow losses like traditional solar cells, giving potential for higher efficiencies. The backside contact design makes it possible to devise easy interconnecting schemes that can significantly simplify production. Furthermore, this design is very well suited for application of conductive adhesives as a replacement of soldering materials containing lead or other toxic metals.

To further improve the existing EWT cell design, the rear side busbars have been omitted. The laser drilled hole pattern can then be spread out over the whole wafer surface increasing the active cell area, which results in higher currents and cell efficiencies. For this cell design however, it is necessary to collect the current from the metal fingers on the rear side separately. Therefore, the fingers are interconnected using a metallised rear side foil on which the cells are glued with a conductive adhesive. This foil takes over the function of the busbars and interconnects the cells.

Apart from optimising the EWT cell design and processing, characterisation of the EWT solar cell prior to interconnection was a major challenge. To solve this problem a special measurement chuck was developed and successfully tested. These activities were completed by the production of a small 9 cell demonstration module using an experimental interconnection foil. Finally first tests on the behaviour of conductive adhesives under accelerated ageing conditions were made by cycling interconnected test structures in a climate chamber.

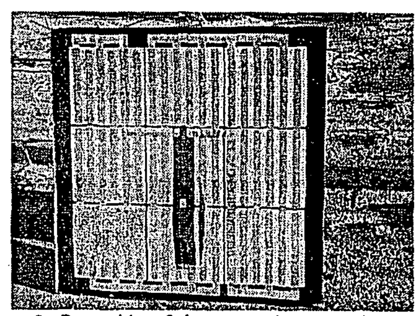

Figure 2: Rear side of demonstration module showing interconnection foil. Cells can be placed very close together to increase active module area.

2. EWT SOLAR CELLS

2.1 Solar Cell Design

In previous work on EWT cell design, the number of emitter wrap-through holes and the geometry of the hole pattern was optimised for lowest series resistance [4]. However, screen printability and processing accuracy prevent the use of the theoretically deduced optimal pattern.

2.2 Processing

The EWT solar cell processing was done using CZ silicon wafers. The processing steps are shown in Figure

3. Further details of the cell processing can also be found in [4] and [5].

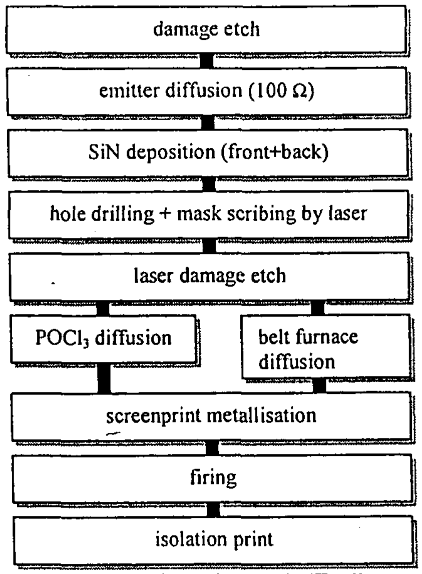

Figure 3: Processing for busbarless EWT cells.

By the two subsequent $POCl_3$ diffusion steps the above outlined EWT solar cell gets a selective emitter. The front surface is lightly doped, while the holes and the rear side emitter contact areas are heavily doped in order to get a low series resistance through the vias together with a good ohmic contacts. To isolate the rear base- and emitter areas, a local SiN layer on the rear side served as a diffusion mask. Openings for both the emitter-contact and the base contact-fingers were laser scribed through the nitride layer. Base contacts are screen-printed aluminium alloyed through the n-type doping.

Finally a ceramic or epoxy based insulating layer is screen-printed. This insulation layer has an alternating pattern of openings above the metal fingers so that six imaginary 'lines' are formed on which the busbars will be glued on later.

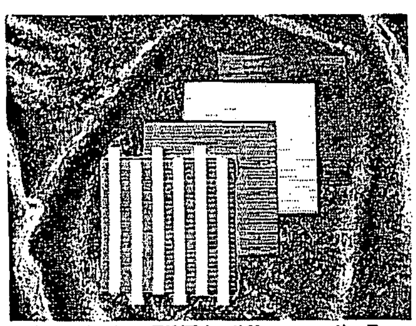

Figure 4: Busbarless EWT in different stadia. From right to left; laser scribing, screen printing of metallisation lines; screen printing of insulation layer; example of busbar strips glued on with conductive adhesive.

2.3 IV-characterisation of the busbarless EWT cell

Obviously a standard IV measurement set-up would short-circuit an EWT cell when connected to the water-cooled measurement chuck. Therefore a special fixture had to be developed. This fixture (see Figure 5) also had to take over the function of the busbars making separate connection to each finger.

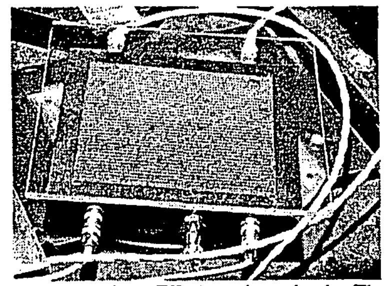

Figure 5: Busbarless EWT testing chuck. The cover glass was necessary to obtain sufficient force between the cell and the electrical probes.

Some compromises had to be made in the design. A glass cover was needed to press the perforated EWT cell onto the 80 measuring probe needles by means of vacuum, because EWT cells leak through their thousands of small holes. While the optical influence of the glass cover can be corrected, the insufficient temperature control lowers the open circuit voltage and efficiency, while the limited number of contact probes might lead to increased series resistance. Both factors result in an underestimation of the cell performance.

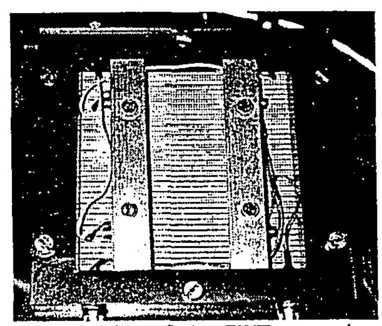

Figure 6: Rear side of the EWT measuring fixture showing the large number of probe needles.

In order to overcome the measurement problems as indicated above, also single cell laminates with EVA were made. Conductive adhesive was applied to connect the cell to the foil and curing of both EVA and the adhesive was done during the lamination cycle.

Best cell result achieved on busbarless EWT cells was 15.6 % efficiency on 100 cm^2 solar cell with the limitations as outlined above.

Table II: Best results busbarless EWT.

J_{SC} (mA/cm^2)	V_{OC} (mV)	FF (%)	Efficiency (%)
37,7	577*	72	15,6

* *The open circuit voltage was low due to the increased temperature of the cell in the text fixture under illumination.*

A V_{OC} versus I_{SC} measurement using a flash-light resulted in a one sun open circuit voltage of 597 mV. This indicates the potential of the EWT cell by neglecting series resistance losses and, due the short duration flashlight, heating-up problems. In Table III the ideal

results (without series resistance losses) of the EWT cell above are shown.

Table III: Flash Isc versus V_{OC} measurement shows ideal cell parameters without series resistance losses.

J_{SC} (mA/cm^2)	V_{OC} (mV)	FF (%)	Efficiency (%)
37,7	597	78	17,4

From these results it must be concluded that series resistance loss is significant. However, a comparison between the bare cells and the single cell laminates glued to the interconnection foil showed no significant difference in fill factor. This indicates that the series resistance caused by the interconnection scheme and the application of conductive adhesives is negligible. Also the EWT test fixture seems to perform satisfactory apart from a rise in cell temperature. Therefore the conclusion must be drawn that the series resistance loss is inherent to the solar cell. Thus in order to optimise the efficiency of the busbarless EWT cell design further series resistance investigations are needed. Possible reasons for the increased series resistance might lie in the non-optimum emitter connecting hole distribution, a high front side emitter sheet resistance or a too low base doping.

3. INTERCONNECTION

3.1 Special Rear Side Foil

On the rear side of the busbarless EWT cell an isolation layer is printed with a symmetrical pattern of openings above the metalisation lines. These openings serve as contact point on which conductive adhesive is screen-printed or dispensed. There are 6 groups of aligned openings that will accommodate the external busbars. Three bars for the emitter contact and 3 for the base contact. Due to pattern symmetry the cells can now be interconnected in a very elegant and simple way.

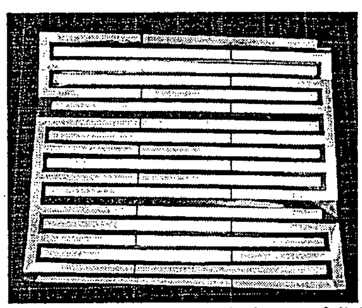

Figure 7: Silver-plated copper /polyester foil laminate for series interconnection of the busbarless EWT minimodule.

An experimental structured foil has been etched to accommodate nine cells. This design can easily be extended for larger modules. After the first cell is placed, the next is placed rotated half a turn, and so on. The emitter contacts from one cell are thus aligned with the base contacts of the next, so that a very simple interconnection foil with straight metal lines can be used. Another advantage is the fact that the cells can be spaced very close together, thereby increasing active module area. The foil also serves as a rear side moisture barrier.

3.2 Module Manufacturing

With the special interconnection foil, module fabrication becomes relatively easy. In the experiments conductive adhesive has been dispensed on the rear side of the cells. In a true series production the adhesive will probably be screen-printed on the foil. On the cell a non-conductive air gap filling material will have to be screen-printed for example a non-conductive adhesive. After lamination no air may be present between the cells and the interconnection foil for obvious reasons. For prototyping no care has been taken to avoid air in the module.

The cells are then placed on the foil and after EVA and a glass plate are placed the module can be laminated. Curing of the conductive adhesive is done together with curing of the EVA in one process step.

4. CONDUCTIVE ADHESIVES

4.1 Introduction

The use of conductive adhesives as an alternative for soldering or other bonding techniques has become very popular in recent years. In a growing number of industrial applications these adhesives are used. A lot of research is done and the number of commercially available products is growing very fast.

Conductive adhesives have many advantages. They are very easy to use, can be dispensed or screen-printed. A wide range of curing temperatures is available. Even curing at room temperature is possible so that low temperature module fabrication comes within reach. Also curing at EVA curing temperature is common so that lamination and curing of the glue can be a single step process. The composition of conductive adhesives can be tuned to fit specific demands like maximum rigidity or the opposite; flexibility to take up stresses when materials with different expansion coefficients are joined. Adhesives can for example be epoxy, acrylic or polyurethane based each with its specific pro's and cons to suit a wide field of applications.

The main disadvantages of conductive adhesives are the higher electrical resistance in comparison with soldered interconnections and the questionable long-term stability under extreme weather conditions present in PV module applications.

4.2 Experiments

To test conductive adhesives for interconnection of busbarless EWT cells a number of experiments have been done and extensive ageing tests have been performed some of which are still running at time of writing.

For the tests three commercially available conductive adhesives have been selected with the demand that they are screen printable and have a curing temperature compatible with EVA of around 150°C. All glues were filled with silver particles and were either on epoxy or acrylic base.

Table I: Main properties of selected conductive adhesives for tests.

	Base	Silver content	Curing	Vol. Res. Ωcm
A	Acrylic1 comp	80.7	125°C/30'	≤4E-4
B	Epoxy 1 comp	70	160°C/15'	≤5E-4
C	Epoxy 2 comp	--	150°C/5'	≤4E-4

In a preliminary experiment tests have been made on aluminium and silver plated substrates using aluminium and plain or silver-plated copper tabs. All curing was done in a laminator. During climate testing however, most of the samples quickly failed so a new test was set up using only silver-plated substrates and tabs. To cure under well-controlled conditions a test set-up was made. With this set-up a defined pressure and curing temperature is achieved, which guarantees reproducible results. (Busbarless EWT single cell modules and mini-module however, have been cured during lamination.)

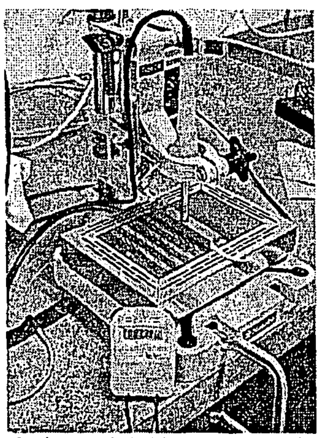

Figure 8: Spring-loaded drill press, soldering iron and hotplate give controllable and accurate curing conditions.

4.3 Test Sample Results

Measurements with a 4-point resistance meter showed that with identical contact surface areas, glued interconnections have comparable electrical resistances to soldered equivalents. The resistance of glued bonds depends strongly on adhesive film thickness. With screen-printing, thicknesses of several tens of μm are achievable giving satisfactory results. Resistances are in the range of several mΩ for a 1 cm^2 contact area.

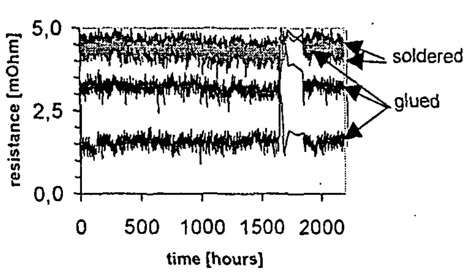

Figure 9: Climate testing shows stable bonds.

Extensive climate testing has been done on these test samples. After almost 2500 hours of continuous high temperature, high moisture no interconnection degradation became visible.

These samples have then been submitted to cycling tests -40/+80°C that are still running at the time of writing. Over 500 hours of cycling have shown no degradation yet. Although this is very encouraging more testing is needed.

5. CONCLUSIONS

It can be concluded from the experiments that busbarless EWT cells showed the required high efficiencies. The interconnection of the fingers from one cell to the other by using conductive adhesives and a rear side interconnecting foil was demonstrated. Single cell laminates were fabricated showing no noticable series resistance losses when compared to the non-interconnected cells.

Conductive adhesives interconnection proves to be a reliable and adequate technique for module fabrication. Low contact resistances and very good climatic test results are a promising perspective for future applications in modules.

Future work is needed to further optimise the EWT cell design and to develop an easy to be applied, reliable isolating layer between the metal fingers and the conductive foil.

More climate tests, especially thermal cycling are needed to investigate degradation of glued interconnections and to guarantee their long term outdoor stability.

6. ACKNOWLEDGEMENTS

The authors would like to thank R. Bethlehem (ECN) for laser processing the wafers and E. Kossen and M. Koppes (ECN) for chemical processing and screenprinting. The excellent co-operation and support from S. Roberts (BP Solar UK) for supplying the wafers and W. Jooss and P. Fath (University of Konstanz) for the $POCl_3$ emitter processing is highly appreciated.

This work has been carried out with financial support of the European Commission within the Ace Designs (JOR3-CT98-0269) and Advantage (ENK6-CT-2000-00340) projects.

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